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Geophysical Investigation at Mustard Gas Burial Ground, Naval Surface Warfare Center, Crane Division, Crane, Indiana

by José L. Llopis, Keith J. Sjostrom, William L. Murphy

WES

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Prepared for Department of the Navy
Southern Division Naval Facilities Engineering Command

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U.S. Army Corps of Engineers
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3909 Halls Ferry Road
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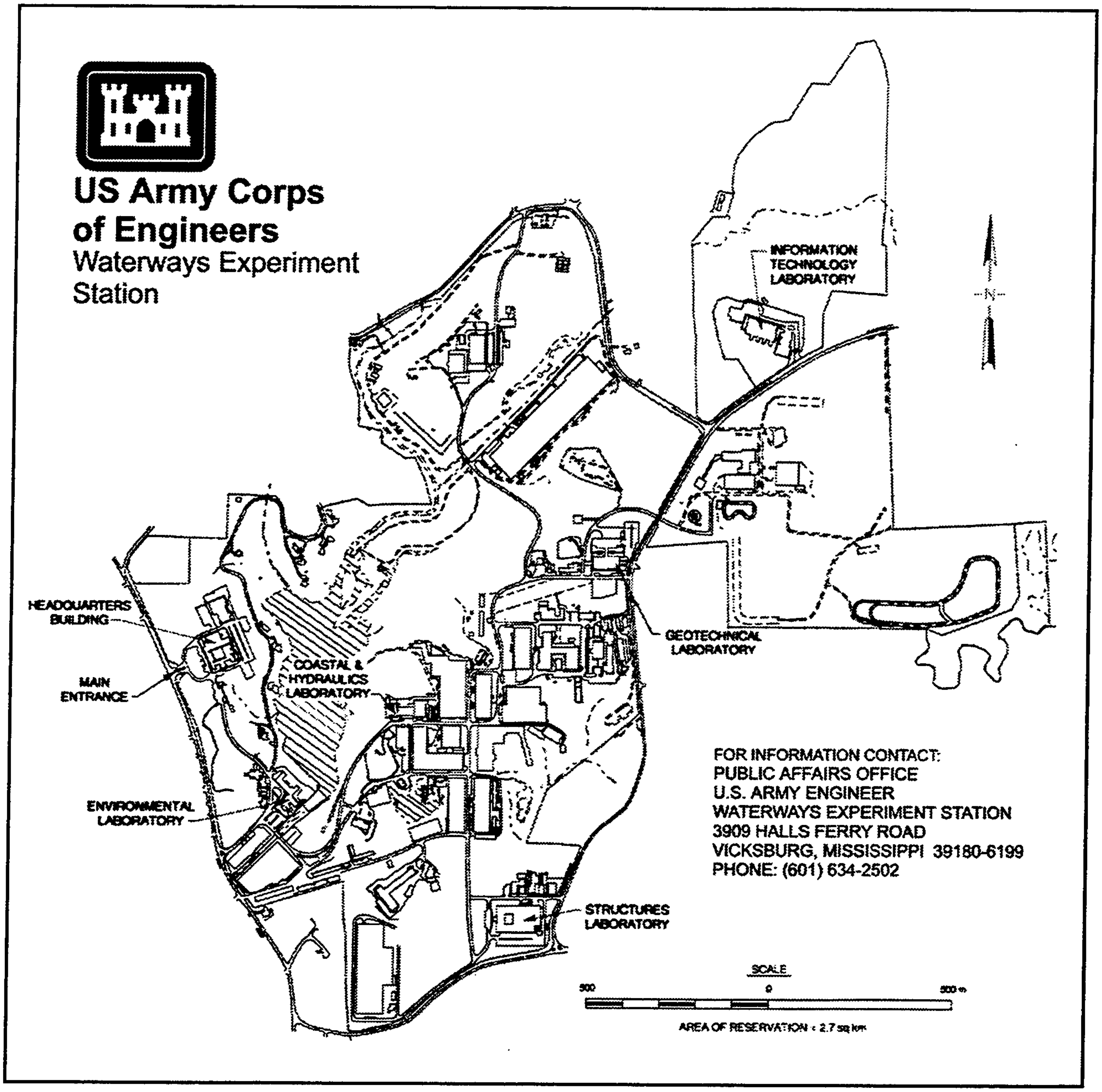

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Contents

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Preface

A geophysical investigation was conducted at the Naval Surface Warfare Center, Crane Division (NSWCCD), Crane, IN, by personnel of the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES), 22 August 1995. The NSWCCD Project Engineer was Mr. Thomas Brent.

This report was prepared by Messrs. José L. Llopis and Keith J. Sjostrom, Engineering Geophysics Branch, Earthquake Engineering and Geosciences Division (EEGD), and Mr. William L. Murphy, Engineering Geology Branch, EEGD. The work was performed under the direct supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch, and Dr. Lillian D. Wakely, Chief, Engineering Geology Branch. The work was performed under the general supervision of Drs. A. G. Franklin, Chief, EEGD, and William F. Marcuson III, Director, GL. The field investigation was performed by Messrs. Llopis, Sjostrom, and Murphy. Data analysis and interpretation were performed by Mr. Llopis.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4046.873	square meters
feet	0.3048	meters
gammas	1.0	nanoteslas
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
millimhos per foot	3.28	milliSiemens per meter

1 Introduction

Background

A sequence of remedial investigations and corrective actions has been performed at the Naval Surface Warfare Center, Crane Division (NSWCCD). Investigations began after the initial discovery in early 1981 of a potential hazardous substance release from the Center. The investigations have proceeded since 1981 and continue at the time of this writing. In April 1981 the U.S. Navy implemented the Navy Assessment and Control of Installation Pollutants (NACIP), now known as the Installation Restoration Program (IRP), to identify and control environmental contamination from past use and disposal of hazardous substances at facilities including the NSWCCD. An Initial Assessment Study (IAS) for the NSWCCD began in April 1981 and was completed in May 1983 by the Naval Energy and Environmental Support Agency (NEESA). Assistance was provided by the Ordnance and Environmental Support Agency and the U.S. Army Engineer Waterways Experiment Station (WES). The IAS recommended site inspections be performed at selected solid waste management units (SWMUs).

On 19 May 1980, the United States Environmental Protection Agency (USEPA) finalized Phase I of the Resource Conservation and Recovery Act (RCRA) hazardous waste regulatory program, which became effective 19 November 1980. The Hazardous and Solid Waste Amendments (HSWA) of RCRA (Section 3004) established corrective actions programs (CAP) at treatment, storage, and disposal (T.D.) facilities. The provision required the NSWCCD to address past releases of hazardous waste or hazardous constituents at solid waste management units and regulated units. A joint RCRA storage permit was issued to the U.S. Navy by the USEPA and the State of Indiana. The Federal portion of the RCRA Permit, dated 20 December 1989, established the HSWA Corrective Action Requirements and Compliance Schedules (RCRA Section 3004). The compliance schedules obligated the NSWCCD to perform RCRA Facility Investigations (RFI) at 30 SWMUs, and if contamination was found, to conduct Corrective Measures Studies (CMS) and implement corrective measures if needed. The State of Indiana obtained pre-HSWA authorization and issued the State portion of the permit.

Comprehensive soil and groundwater release assessment and release characterization investigations have been completed and technical reports submitted for several SWMUs within NSWCCD. The NSWCCD reviewed all of the facility's

30 SWMUs to determine which ones had characteristics that suggest they may be amenable to accelerated interim measures. In the summer of 1993 the Navy decided to implement remedial action through interim measures at those SWMUs for which sufficient site assessment and characterization data were available. Proposed remedial actions include interim corrective measures consisting of geophysical surveying, exhumation, confirmation sampling, and long-term monitoring at the Mustard Gas Burial Ground (MGBG).

Site Description and History of Site Operations

Naval Surface Warfare Center, Crane Division

The NSWCCD is located in southwest IN approximately 75 miles southwest of Indianapolis and 71 miles northwest of Louisville, KY (Figure 1). The NSWCCD occupies 62,463 acres (approximately 100 square miles) of the northern portion of Martin County and small portions of neighboring Greene, Daviess, and Lawrence Counties. NSWCCD provides materiel, technical, and logistic support to the Navy for equipment, weapons systems and expendable and nonexpendable ordnance items. The facility was opened in 1941 as the Naval Ammunition Depot, Burns City, to serve as an inland munitions production and storage center. The name became Naval Surface Warfare Center, Crane in 1992. The Department of Defense ammunition procurement responsibility was transferred to the Army in 1977. The Army has assumed ordnance production, storage, and related responsibilities under the single service management directive. All environmental activities on the installation, including permitting activities, remain the responsibility of the Navy.

Mustard Gas Burial Ground (MGBG)

The MGBG is located in the southeast corner of NSWCCD adjacent to Road 251, which is accessible from NSWCCD Highway 161 (Figure 2). The MGBG is located between storage bunkers 1409 and 1407. The site is atop a broad ridge with gently rolling topography and approximately 5 to 10 feet of relief from the southeastern to northwestern boundary of the site. The MGBG is defined by a roughly rectangular shaped perimeter fence approximately 350 by 250 feet enclosing an area of just over two acres. The perimeter fence and trees within the boundary were removed in April 1995 to prepare for the survey. Four creosoted timbers at each corner were left in place to mark the MGBG boundary. The site was mowed by a NSWCCD contractor during the week of 14 August 1995.

Objectives

Personnel from WES conducted a geophysical investigation at NSWCCD on 22 August 1995. The objective of the investigation was to detect and delineate anomalies indicating the locations of buried structures, objects, or disturbed zones

associated with past hazardous waste burial at the MGBG. Electromagnetic (EM) and magnetic survey methods were used to meet this objective.

2 Geophysical Test Principles and Field Procedures

Geophysical Test Principles

Electromagnetic surveys

The EM technique is used to measure differences in terrain conductivity. Like electrical resistivity, conductivity is affected by differences in soil porosity, water content, chemical nature of the groundwater and soil, and the physical nature of the soil. For a homogeneous earth, the true conductivity is the reciprocal of the true resistivity. Some advantages of using the EM over the electrical resistivity technique are (1) less sensitivity to localized resistivity inhomogeneities, (2) no direct contact with the ground required, thus no current injection problems, (3) smaller crew size required, and (4) rapid measurements (McNeill 1980). Geonics, Ltd. EM instruments, models EM 31 and EM 61, were used to survey the site. The EM 31 operates in the frequency-domain whereas the EM 61 operates in the time-domain.

The EM 31 is a frequency-domain electromagnetic instrument consisting of a coplanar transmitter and receiver coil set a fixed distance apart. The transmitter coil is energized with an alternating current at an audio frequency (KHz range) to produce a time varying magnetic field that in turn induces small eddy currents into the ground. These currents generate secondary magnetic fields that are sensed, together with the primary field, by the receiver coil.

There are two components of the induced magnetic field measured by the EM 31 equipment. The first is the quadrature phase component, which gives the ground conductivity measurement. The units of conductivity are millimhos per foot (mmho/ft) or, in the SI system, milliSiemens per meter (mS/m). The second component is the inphase component, which is used primarily for calibration purposes. However, the inphase component is much more sensitive to large metallic objects and therefore very useful when looking for buried metal containers (Geonics 1984). When measuring the inphase component, the true zero level is not known since the reference level is arbitrarily set by the operator. Therefore, measurements

collected in this mode are relative to an arbitrary reference level and have units of parts per thousand (ppt).

The EM 31 has an intercoil spacing of 12 ft and an effective depth of exploration of about 20 ft (Geonics 1984). The EM 31 meter reading is a weighted average of the earth's conductivity as a function of depth. A thorough investigation to a depth of 12 ft is usually possible, but below that depth the effect of conductive anomalies becomes more difficult to distinguish. The EM 31, when carried at a usual height of approximately 3 ft, is most sensitive to features at a depth of about 1 ft. Half the instrument's readings result from features shallower than about 9 ft, and the remaining half from below that depth (Bevan 1983). Figure 3 more clearly illustrates the effect of depth on instrument sensitivity with the dashed lines depicting the sensitivity of the instrument to objects between it and the ground surface. The instrument can be operated in both a horizontal and vertical dipole orientation with correspondingly different effective depths of exploration. The instrument is normally operated with the dipoles vertically oriented (coils oriented horizontally and coplanar) which gives the maximum depth of penetration. The instrument can be operated in a continuous or a discrete mode.

The EM 61 is a high-sensitivity, high-resolution time-domain metal detector which is used to detect both ferrous and nonferrous metallic objects. Unlike the EM 31, which applies a continuous alternating current to a coil and measures the secondary magnetic field while the transmitter is operating, the EM 61 generates a pulsed primary magnetic field, which induces eddy currents in nearby metallic objects. The decay of these currents is measured by two receiver coils mounted on the coil assembly. To eliminate the effects of conductive soils, which have a shorter decay rate than those of metals, the secondary magnetic field response is not measured until a few microseconds after the transmitter is turned off.

The EM 61 consists of two horizontal and parallel coils, each approximately 3.3 ft square, one positioned approximately 16 in. above the other. Wheels are attached to the lower coil so the instrument can be pulled along the survey line. In cases where the terrain does not permit use of wheels, the coil assembly can be strapped to the operator using a specially designed harness. The two configurations are illustrated in Figure 4. The lower coil, channel 2, is located approximately 16 in. above the ground surface. The received signal is measured using both coils, allowing a measurement at two depths of investigation and a differential reading. The measured signal is in units of millivolts (mV). The EM 61 can detect a single 55 gallon drum at a depth of approximately 10 ft beneath the instrument, yet is relatively insensitive to interference from nearby surface metal such as fences, buildings, cars, etc. (Geonics 1993).

The EM 61 data can be input into a software program that calculates the apparent depths to buried targets. The computed apparent depths are quite accurate when there is a single target with a diameter less than 3 ft (smaller than the dimensions of the coils) and when the coils are directly over the target

(Geonics 1994). When the target is greater than 3 ft in width, the apparent depth will be greater than the true depth. Also, if buried metallic material is not directly beneath the survey line incorrect depths will be computed.

The EM 31 and EM 61 data can be presented in profile plots or as isoconductivity contours, if data are obtained in a grid form. A more thorough discussion on EM theory and field procedures is given by Butler (1986), Telford et al. (1973) and Nabighian (1988).

Magnetic surveys

The magnetic method of surveying is based on the ability to measure local disturbances of the earth's magnetic field. Magnetic anomalies are caused by two different types of magnetism: induced and remanent magnetization. Remanent magnetization is a permanent magnetic moment per unit volume whereas induced magnetization is temporary magnetization that disappears if the material is removed from a magnetic field. Generally, the induced magnetization is parallel with and proportional to the inducing field (Barrows and Rocchio 1990). The remanent magnetism of a material depends on the thermal and magnetic history of the body and is independent of the field in which it is measured (Breiner 1973).

A GEM Systems GSM-19 "walking" proton precession magnetometer was used to measure the total field intensity of the local magnetic field. The magnetic unit of measurement is the nanotesla (nT) or gamma (γ). One nanotesla is equivalent to one gamma. The local magnetic field is the vector sum of the field of the locally magnetized materials (local disturbance) and the ambient (undisturbed) magnetic field. Figure 5 shows the ambient earth's field as 50,000 nT with a local disturbance of 10 nT. Figure 5 shows that the quantity measured with the magnetometer is the resultant total field with a value of 50,006 nT. The GSM-19 magnetometer has an absolute accuracy of approximately ± 1 nT. For reference, the earth's magnetic field varies from approximately 60,000 nT at the poles to 30,000 nT at the equator.

A magnetic anomaly represents a local disturbance in the earth's magnetic field that arises from a localized change in magnetization, or magnetization contrast. The observed anomaly expresses the net effect of the induced and remanent magnetization and the earth's ambient magnetic field, and depends on its mass, magnetization, shape and orientation, and state of deterioration. Detection of the anomaly and hence the localized subsurface feature depends on the magnitude and spatial wavelength relative to local magnetic noise and anomalies caused by other magnetic sources.

Field Procedures

The surveyed area at the MGBG measured approximately 220 ft by 340 ft as shown in Figure 6. A grid system was established and grid station markers staked out across the area of interest. The grid stations were marked at 20 ft intervals by

implanting polyvinylchloride (PVC) stakes into the ground. An initial line was laid between the southeast and southwest creosoted corner fence posts for a distance of 340 ft. A right angle was turned to the northeast from the southwest corner to establish the other leg of the grid. The approximate locations of the two base line corner fence posts were established by taping to two adjacent monitoring wells.

The EM 31 and EM 61 measurements and GSM-19 magnetic readings were collected along northwest-southeast oriented survey lines spaced 10 ft apart. The EM 31 readings were taken at 10-ft station intervals along each survey line whereas EM 61 and GSM-19 magnetic readings were taken at approximately 4-ft station intervals. No readings were taken in the wooded region of the site shown in Figure 6. The EM 31 data were taken in both the quadrature phase (conductivity) and inphase mode at each measurement station. The geophysical data were collected, recorded, and transferred to a laptop computer at the conclusion of the survey for storage and future processing.

3 Test Results and Interpretation

In deciding what constitutes significant anomalies for a particular site several factors must be weighed. Anomaly detection is limited by instrument accuracy and local "noise" or variations in the measurements caused by factors not associated with the anomalies of interest such as fences, power lines, metal buildings, etc. (cultural noise). For the anomaly to be significant, the measurement due to the anomaly must have a response greater than that due to the interfering cultural noise. Since the anomaly amplitude, spatial extent, and wavelength are the keys to detection, the size and depth of the feature causing the anomaly are important factors in determining detectability and resolution. The intensity of the anomaly is also a function of the degree of contrast in material properties between the anomaly and the surrounding material.

The results of the EM 31 conductivity, EM 31 inphase, EM 61 channel 2 response, EM 61 differential response, and total magnetic field surveys are presented in Figures 7 through 11, respectively. The EM 61 channel 2 and differential response plots are presented to aid in distinguishing near surface objects from deeper targets. The channel 2 response (bottom coil response) contains information about all targets within reach of the EM 61 including shallow and deep targets responses. On the other hand the differential channel (top coil minus bottom coil response) emphasizes mostly deeper targets with removed or largely suppressed response from near surface material.

All of the geophysical survey results indicated an anomaly, approximately 10 ft in diameter, centered on Sta. 255 of Line 130. The EM 61 survey reduction program indicates that this is a shallow anomaly approximately 1 to 2 feet deep. The above anomaly is presumed to be caused by buried ferro-metallic material since it was also detected by the magnetic survey. The EM 61 survey also indicates a small, 2 to 3-ft diameter, anomaly located at Sta. 290 along Line 160 with a computed depth of approximately 1.5 ft. This small anomaly is caused by metallic material. It is possible that this anomaly may also be caused by ferrous metal but since the material or object causing the anomaly is small, it was not detected by the magnetometer. The EM 61 surveys (Figures 9 and 10) show a series of small bull's-eye type anomalies, spaced about 20 feet apart, along Line 0. Line 0 runs from the southeastern to the northwestern creosoted corner posts and along an old

fence line. These anomalies are presumed to be caused by the remains of metal fence posts because of the regularly spaced anomalies. These anomalies were probably too small to be detected by the other survey methods.

No other anomalies were detected at the site. The gradual variation in the EM 31 conductivity and inphase values, shown in Figures 7 and 8, respectively, is presumed to be a reflection of soil type and/or soil moisture changes and not caused by the presence of burial trenches or buried metallic objects. Also, the anomalously low inphase values along the northern border of the site (Figure 8) are assumed to be caused by a linear shift in values as a result of bumping the EM 31 instrument against a tree while surveying in the wooded section of the site. These anomalous values are not associated with burial trenches or buried metallic objects.

4 Summary

A geophysical investigation using EM and magnetic survey methods was conducted at NSWCCD to detect and delineate anomalies indicating the locations of buried structures, objects, or disturbed zones associated with past hazardous waste burial at the MGBG. One strong anomaly located along Line 130 at Sta. 255 was detected by all of the surveys. The anomaly is interpreted to be caused by ferrous material since it was detected by the magnetometer. The anomaly is about 10 ft in diameter and 1 to 2 feet deep. A second, smaller anomaly caused by nonferrous metallic material was detected using the EM 61 meter along Line 160 at Sta. 290. The interpreted depth of this anomaly is approximately 1.5 ft. A series of small anomalies detected along an old fence line and corresponding to Line 0 are presumed to be caused by remanent of metal fence posts. No other anomalies, indicative of the locations of buried structures, objects, or disturbed zones associated with past hazardous waste burial at the MGBG, were identified.

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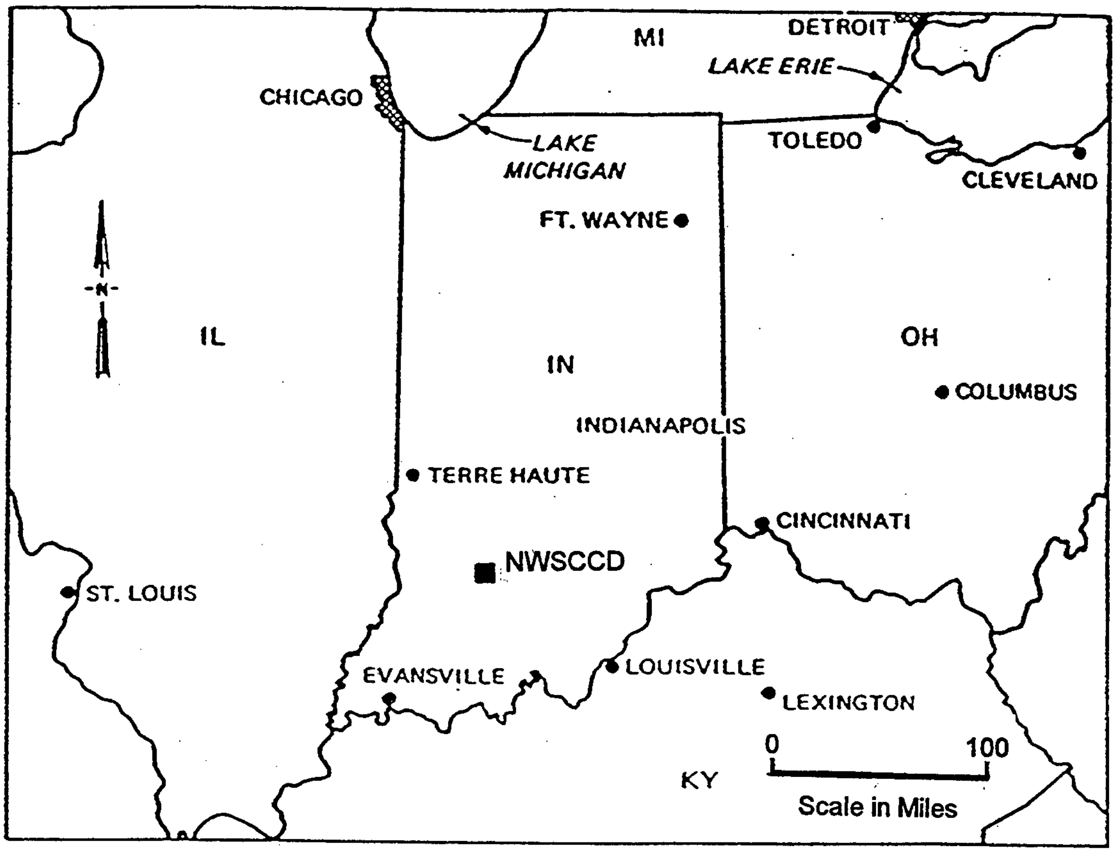

Figure 1. Location of Naval Surface Warfare Center,
Crane Division (NSWCCD), Crane, IN

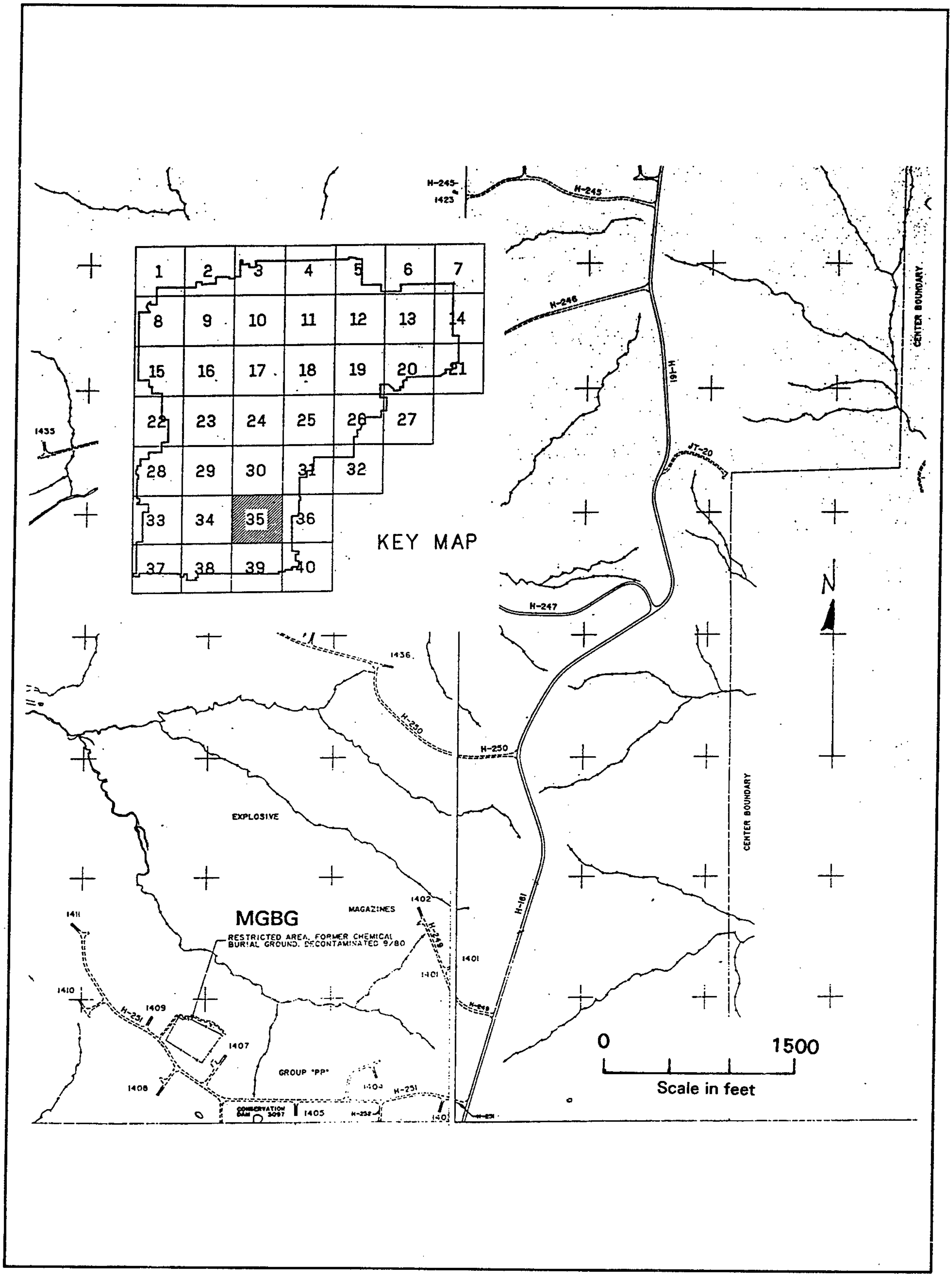

Figure 2. Location of Mustard Gas Burial Ground (MGBG)

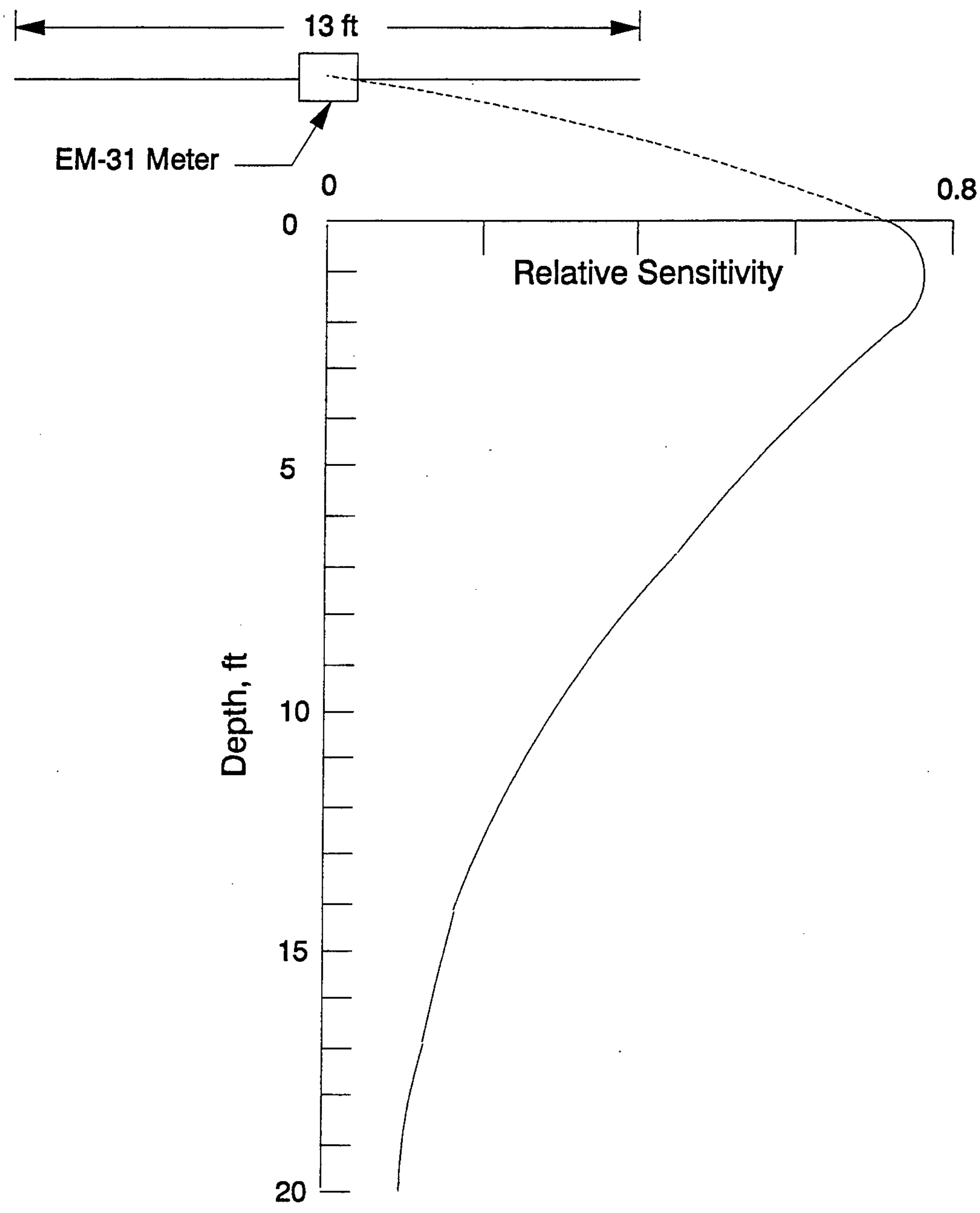

Figure 3. Sensitivity versus depth for the EM-31 terrain conductivity meter

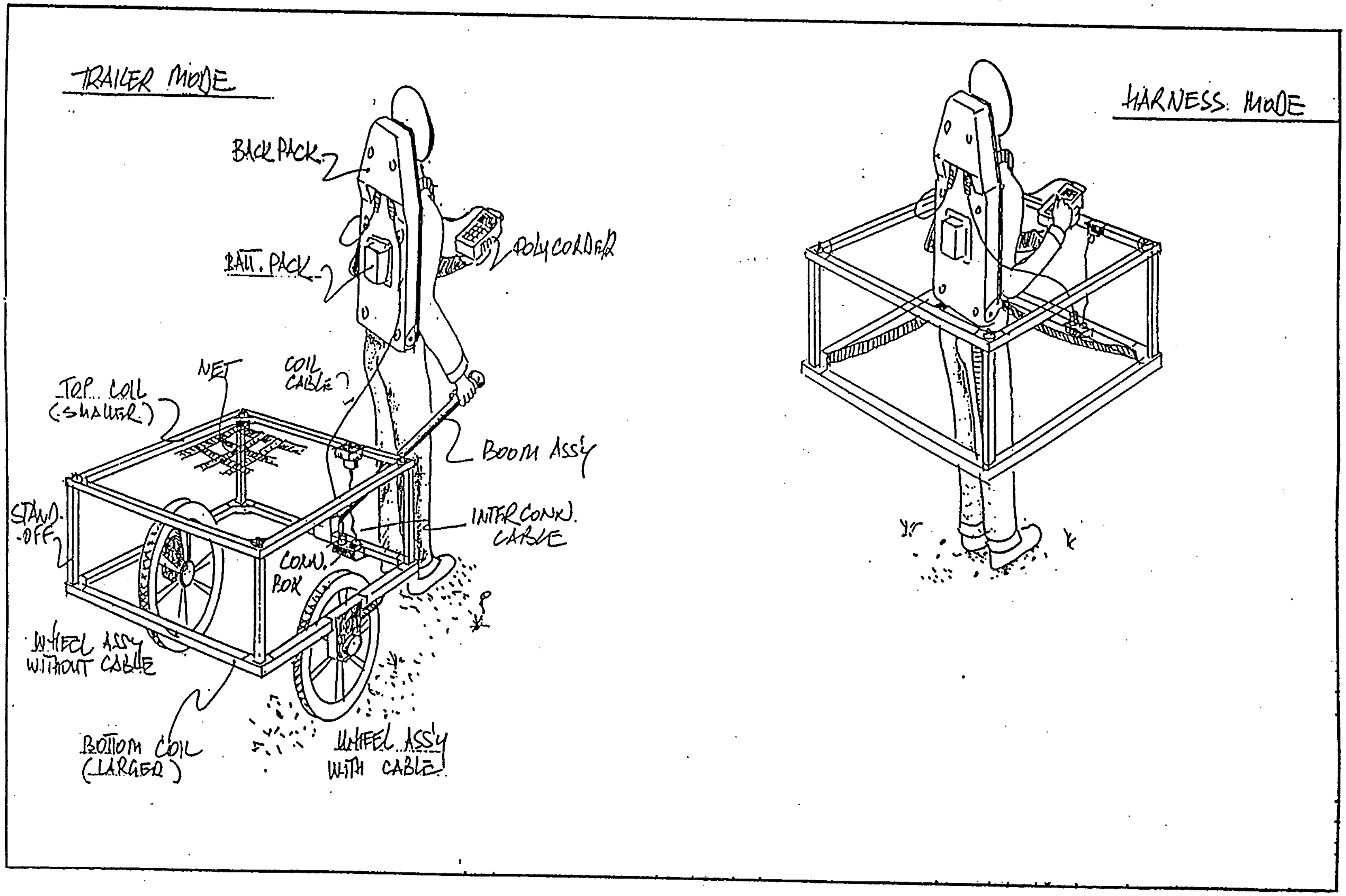

Figure 4. EM 61 trailer and harness configurations (after Geonics Ltd. 1993)

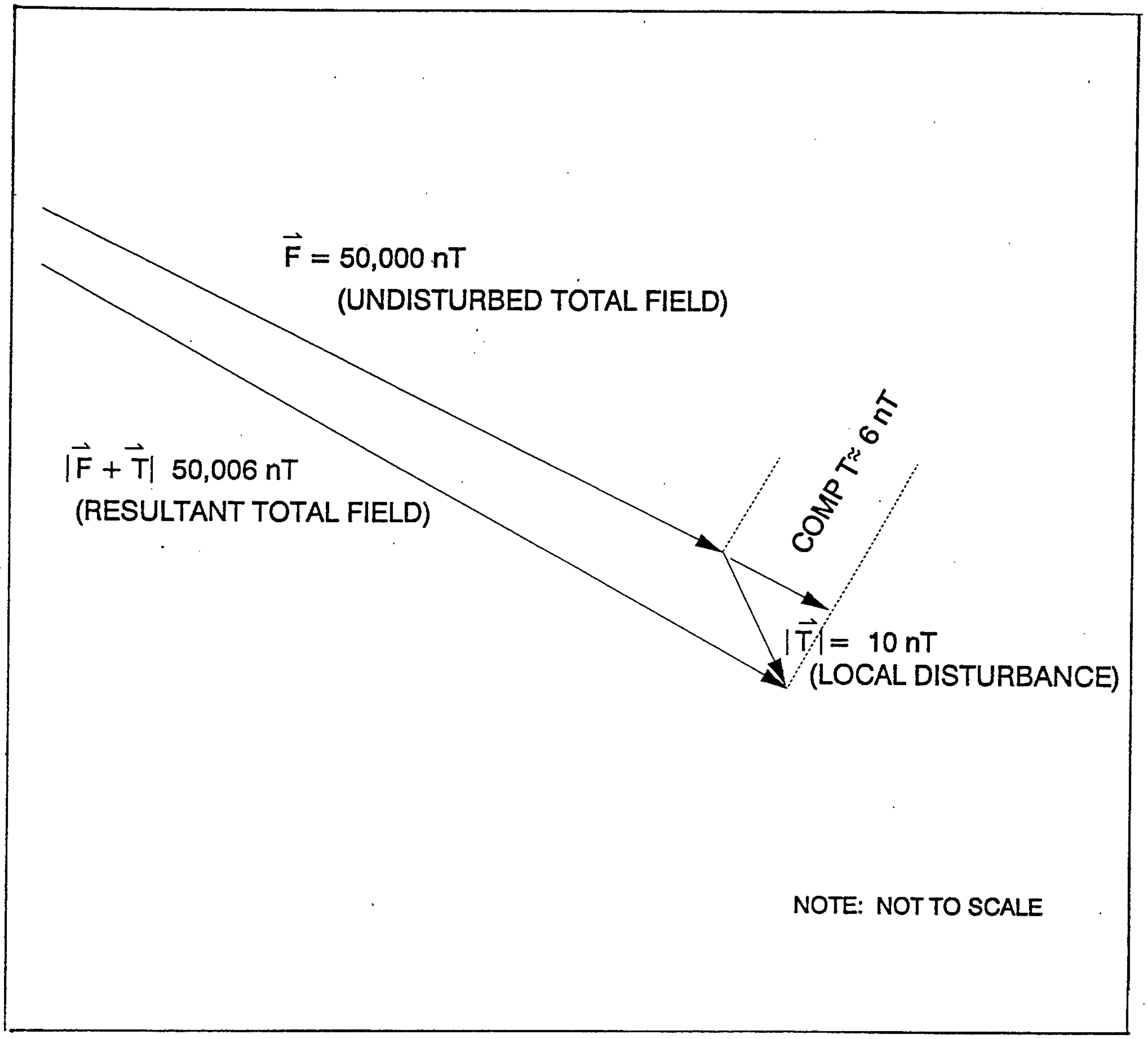

Figure 5. Local perturbation of the total field vector (after Breiner 1973)

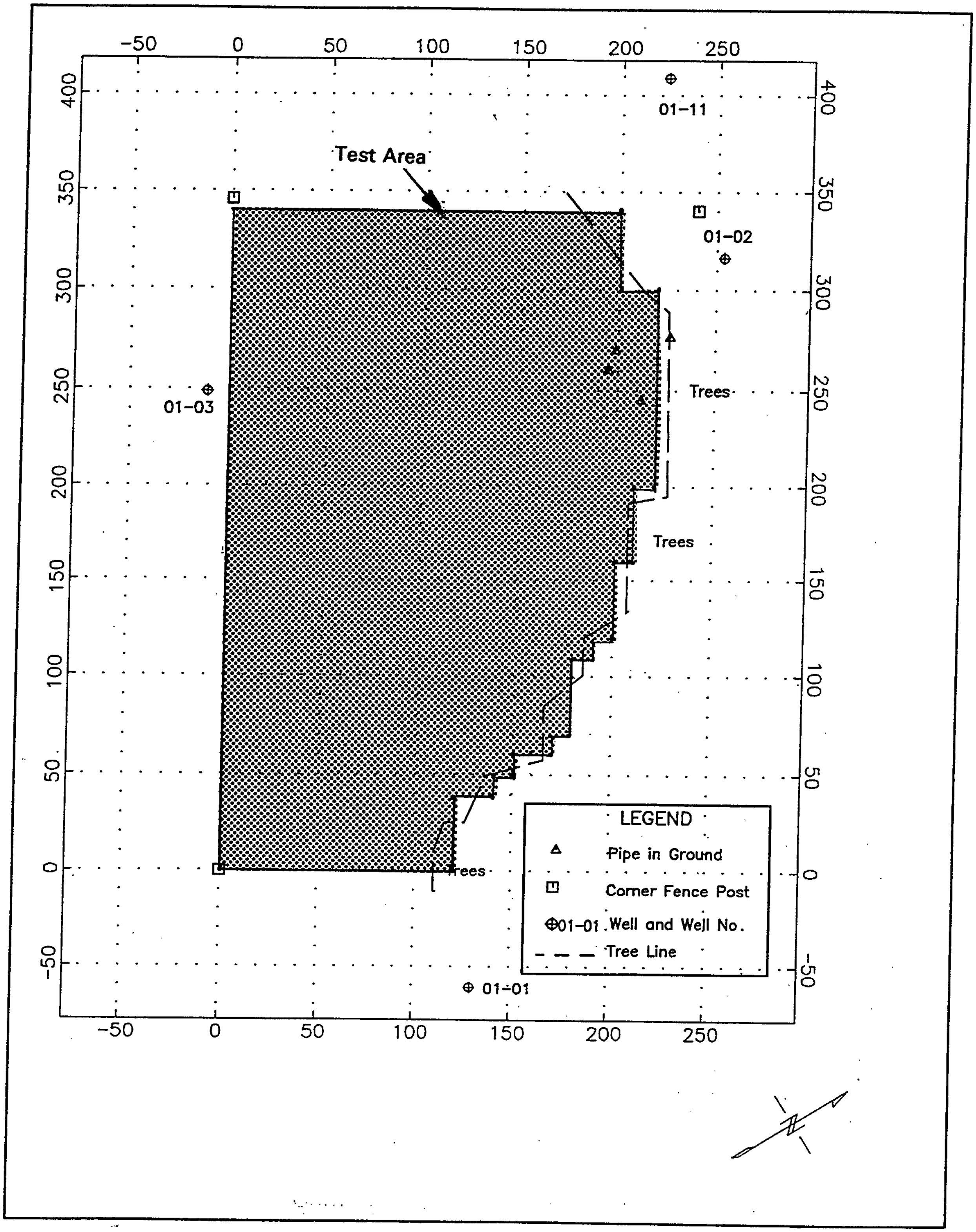

Figure 6. Layout of Mustard Gas Burial Ground (MGBG)

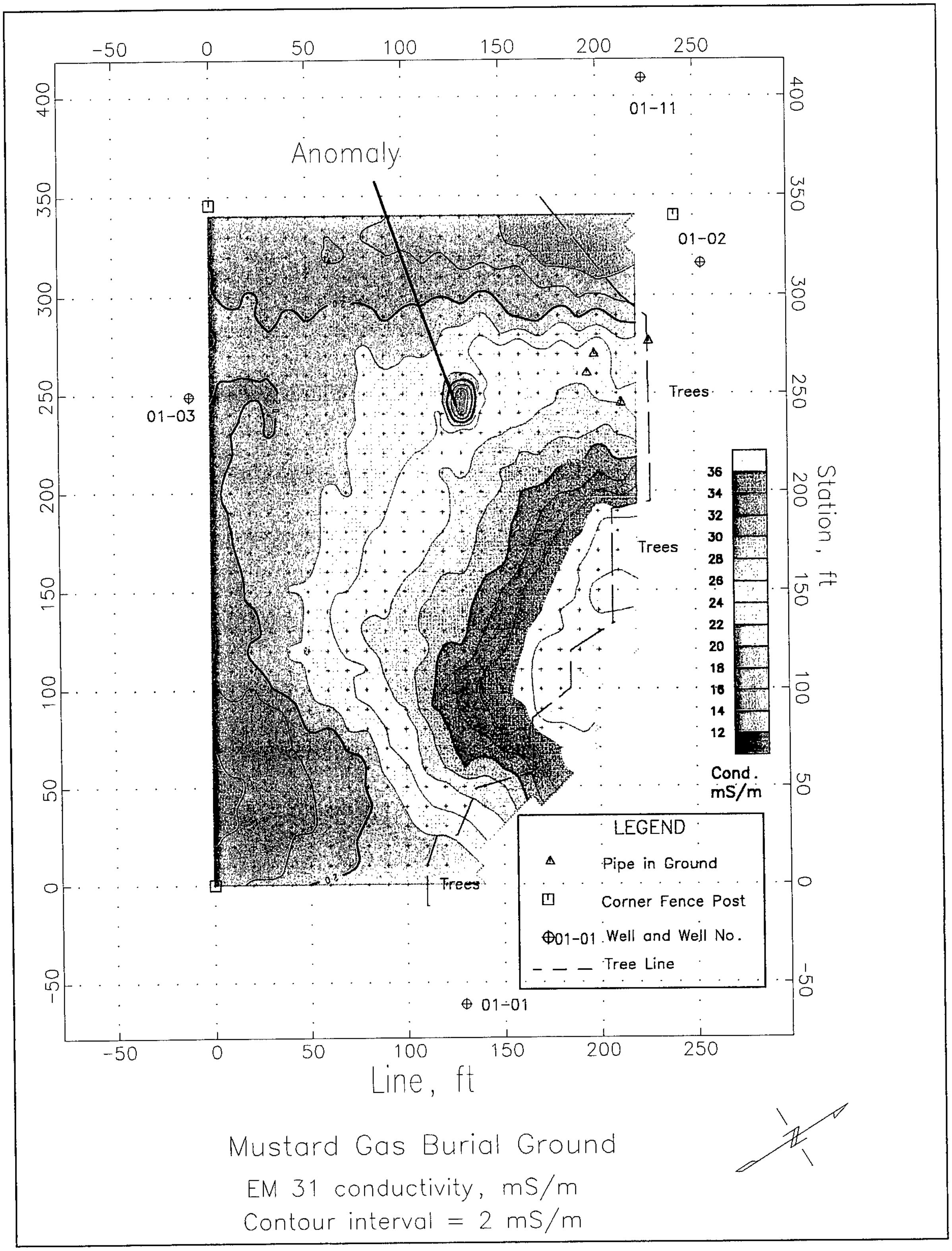

Figure 7. MGBG conductivity survey results

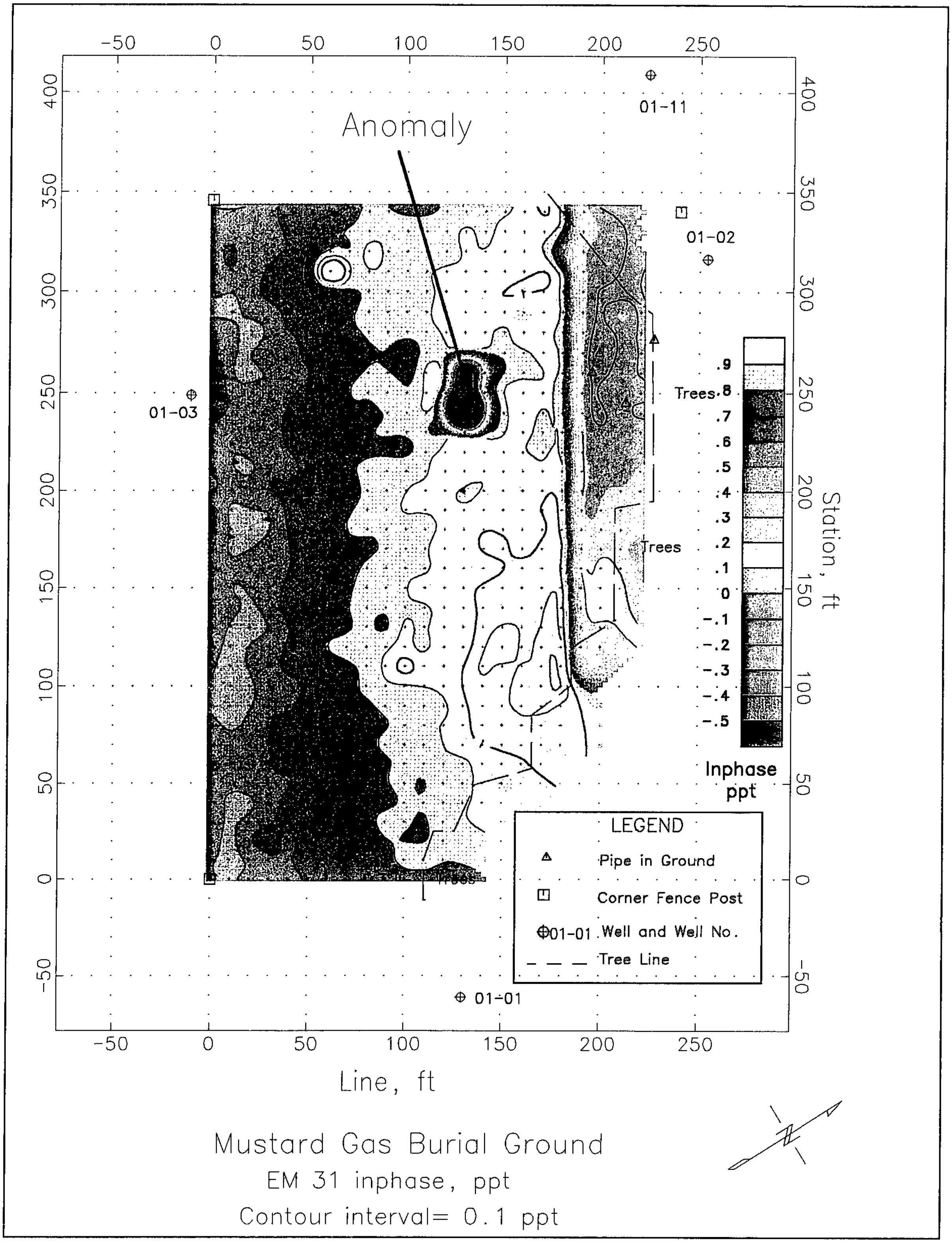

Figure 8. MGBG inphase results

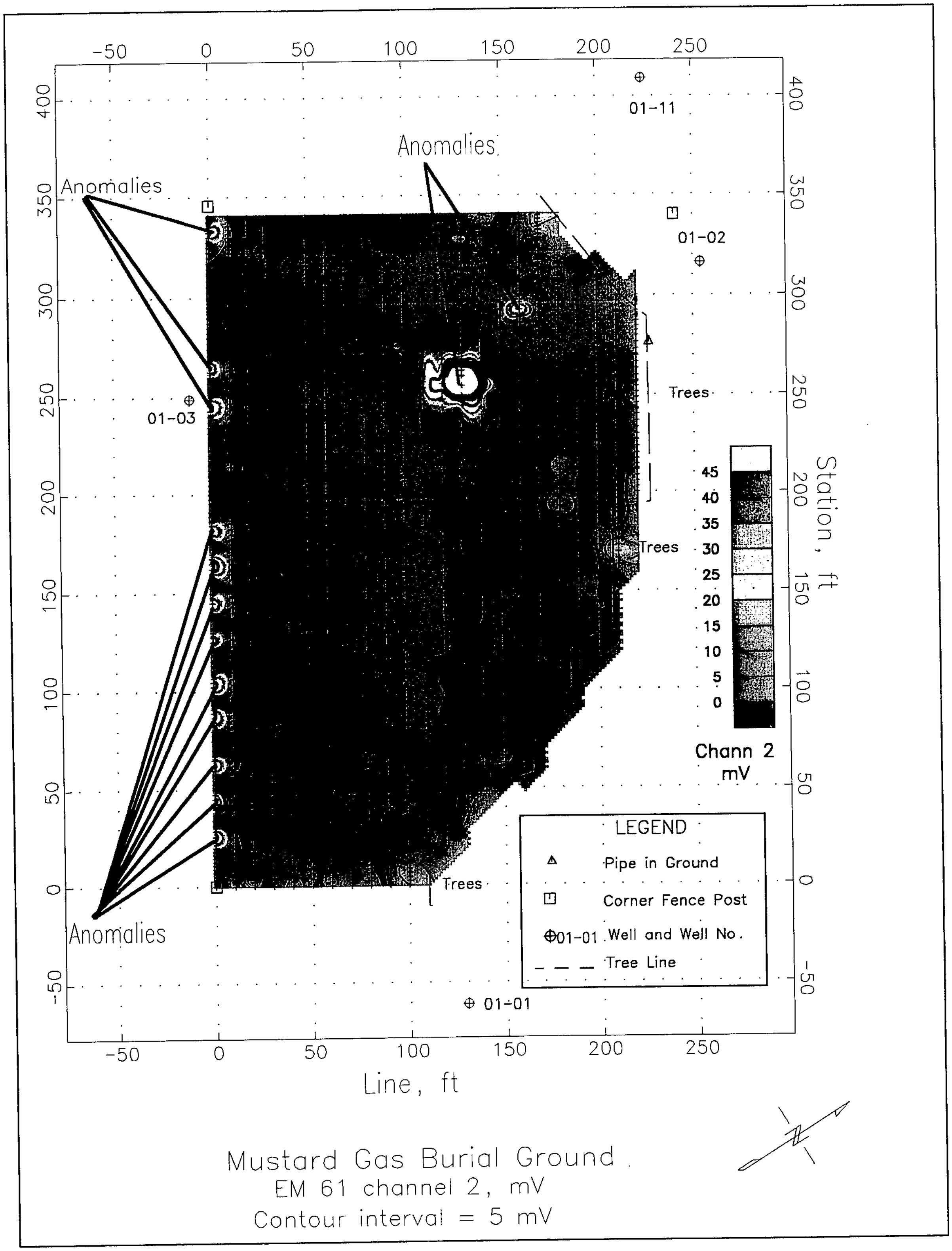

Figure 9. MGBG EM 61 Channel 2 results

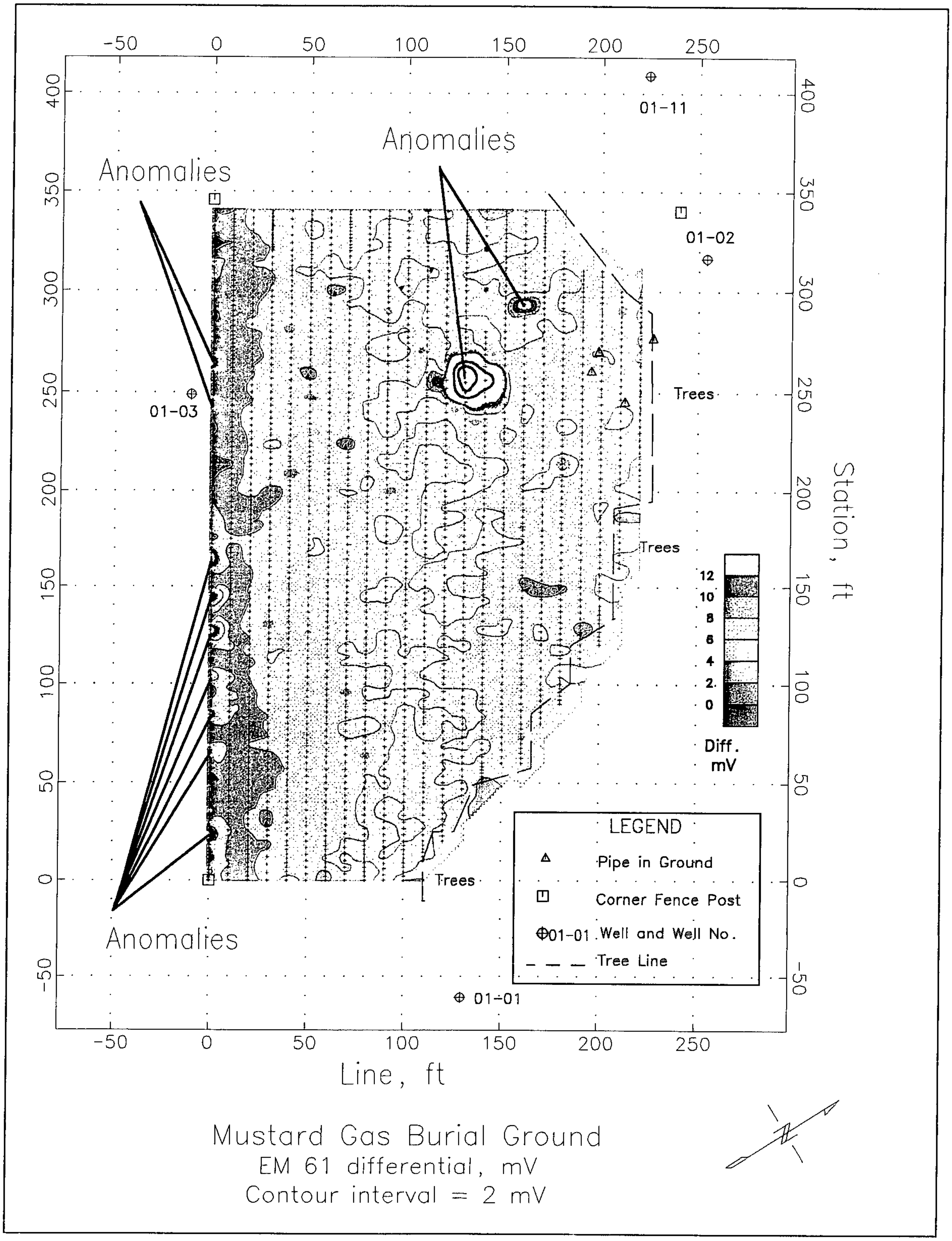

Figure 10. MGBG EM 61 differential (Channel 1 minus Channel 2) results

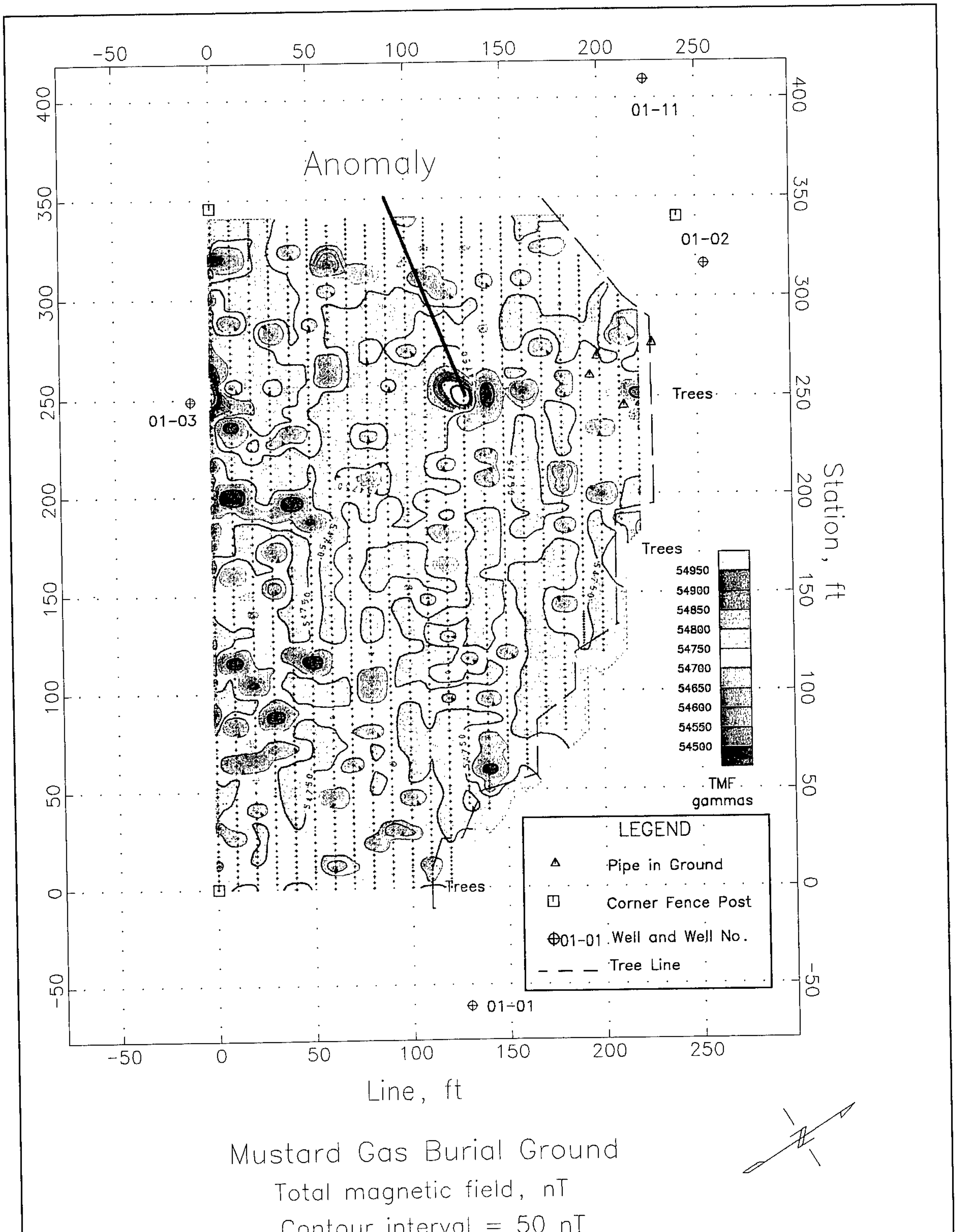

Figure 11. MGBG total magnetic field results

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13. ABSTRACT *(Maximum 200 words)*

A geophysical investigation was conducted at the Mustard Gas Burial Ground (MGBG) at the Naval Surface Warfare Center, Crane Division, Crane, IN. The MGBG, an approximately 2-acre area, is a former Solid Waste Management Unit. The objective of the investigation was to detect and delineate anomalies indicating the locations of buried structures, objects, or disturbed zones associated with past hazardous waste burial at the MGBG. The locations of these objects are needed so they can be excavated for removal to a permanent treatment or disposal site.

Frequency and time-domain electromagnetic (EM) along with magnetic survey methods were used at the MGBG. All the surveys performed at the MGBG indicated an anomalous area approximately 10 ft in diameter centered on Station 255 on Line 130. The estimated depth of the anomaly, based on results of the transient EM surveys, is 1 to 2 ft. The anomaly is presumed to be ferrous in nature since it was detected by the magnetometer. An additional, 2- to 3-ft diameter anomaly, caused by a small metallic object was detected by the transient EM surveys. This anomaly is located at Station 290 along Line 160 and is approximately 1.5 ft deep. A series of small bull's-eye type anomalies spaced at about 20 ft apart along Line 0 were detected by the transient EM surveys. These anomalies are presumed to be the remains of metal fence posts. No other anomalies, indicative of the locations of buried structures, objects, or disturbed zones associated with past hazardous waste burial at the MGBG, were identified.

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